Introductory Chapter: Overview of Nanofibers

Mohammed Muzibur Rahman

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/64370

The book Nanofiber Research - Reaching New heights contains ten chapters divided in four sections. Section 2, "State-of-the-Art Biomaterials," deals with the preparation and characterization of bio-fibers as well as nanofibers for scaffolds as promising cell carrier for tissue engineering. In Section 3, "State-of-the-Art Polymers," the advanced research of electrospinning and electrospraying methods for designing antimicrobial polymeric biocomposite mats and natural medicinal plant polymer for cosmeceutical applications is presented here. The fourth section "State-of-the-Art Nanocomposites" is describing the synthesis and characteristics of carbon nanofibers (CNFs)/silicon composites and application to materials of Li secondary batteries. The final, fifth section "State-of-the-Art Nanomaterials" deals with the preparation, characterization, and potential applications of electrospun metal oxide nanofibers, titanium thin-film nanofibers, and hierarchical crystalline nanofibers on the Cooperative Phenomena of Functional Molecular Group as the Target of Expression of New Physical Properties.

Nanofibers are defined as fibers with diameters less than 100 nm. In the fabric industry, this classification is often extended to include fibers as large as 1,000 nm diameter, which referred to microfibers. Generally, fibers can be prepared by melt processing, interfacial polymerization, electrospinning, antisolvent-induced polymer precipitation, and electrostatic spinning [1], whereas carbon nanofibers are graphitized fibers produced by catalytic synthesis [2]. Here, nanoscale fibers are an interesting noble type of fiber materials that significantly utilized as different doping for momentous applications such as energy storage, fuel cells, aerospace, diodes, capacitors, transistors, drug delivery systems, battery separators, sensors, and information technology [3,4]. Metal oxide nanofibers were made from different sorts of inorganic precursors by different conventional methods. The most regularly mentioned ceramic semiconductor materials with nanofiber surface morphology are TiO_2, SiO_2, lithium titanate, ZrO_2, Al_2O_3, titanium nitride, or platinum. Preparation techniques include direct drawing from a precursor solution, melt processing in furnace, antisolvent-induced polymer precipitation, spinning, electrospinning, or "landmass in the ocean."

One-dimensional magnetic nanostructures have lately attracted much attention due to their intriguing characteristics that are not showed by their bulk or nanoparticle counterparts. These metal oxide nanostructures are also significantly useful as active chemical components for ultrahigh-density data storage in the fabrication of selective and sensitive sensors and spintronic chips or devices [5]. Electrospinning denotes a suitable technique to producing polymer materials along low diameters ranging from nano- to micrometers. The spinning route comprises the application of higher voltage to a micro-capillary that is attached to a reservoir clutching the precursors of polymeric solution. Under the effect of high electric field, a hanging droplet of the monomer solution at the capillary strip can be distorted into the narrowed shape. When the ground strength has outstripped a threshold to overwhelm the surface pressure, electrostatic forces are caused by the discharge of a thin, charged jet. The jet undergoes a whipping technique, which guided to the development of ultrathin fibers as a consequence of solvent evaporation. These nanofibers with significantly moderated diameters foldaway toward a grounded conductor under the accomplishment of the modified electric field and lastly can be accumulated in the form of long threads. Generally, the nanofibers that are deposited on the surface of a conductor form nonwoven mats that are illustrated by higher surface coverage and relatively small pore sizes. By adjusting the design of an accumulator, it is promising to accumulate the thin nanofibers as uniaxially aligned nano-arrays [6–8].

In this book, M. Lizuka et al. focused on “Control of Hierarchical Structure of Crystalline Nanofibers Based on the Cooperative Phenomena of Functional Molecular Group as the Target of Expression of New Physical Properties” where the functional nanofibers were introduced. Here, the formation of nanofiber morphology at a mesoscopic scale and molecular level stacking of a tetrathiafulvalene (TTF) derivative with a chiral group were investigated by the one-dimensional growth method in interfacial molecular films. The growth of morphology is encouraged by the application of the one-dimensional growth method at low-surface pressure conditions, varying compression speeds and sub-phase temperatures. Later on, the formation of nanofiber morphology at a mesoscopic scale and molecular level packing of an amphiphilic diamide derivative with two hydrocarbons were evaluated by the interfacial molecular films. Authors H. Rodríguez-Tobías et al. have discussed about “Electrospinning and Electrospraying Techniques for Designing Antimicrobial Polymeric Biocomposite Mats.” Here, they approached on electro-hydrodynamic techniques, namely, electrospraying and electrospinning, which are powerful methods for developing material with morphological features suitable for tissue engineering applications. The incorporation of nanoparticles allows for the generation of multifunctional mats that were used in different applications ranging from filters for pollutant removal to wound dressings. Regarding the pollutant removal, zinc oxide (ZnO) and TiO_2 were the more promising nanoparticles for tissue engineering. Authors J. H. Yeum et al. have focused on “Novel Natural Polymer/Medicinal Plant Extract Electrospun Nanofiber for Cosmeceutical Application” where they approached on zein produced from maize is a hydrophobic protein, which holds great potential for a number of industrial applications, for example, packaging, food, pharmaceutical, cosmetic, and biomedical industries. Here, they studied the influence of cosolvent ratio and concentration of zein/medicinal plant extract on the morphologies of nanostructured zein/medicinal plant extract nanomaterials prepared by electrospinning technique from ethanol/water solution. Zein/medicinal extract nanofibers

http://dx.doi.org/10.5772/64370

were characterized in details by field emission scanning electron microscopy, transmission electron microscopy, thermogravimetric analysis, and differential scanning calorimetric techniques. They also worked to incorporate medicinal plant resources into the electrospun zein nanofibers by electrospinning technique to investigate the effect of medicinal extract on the morphologies, antibacterial, antioxidant, and other properties. Authors Y. Liao et al. approached on "Electrospun Metal Oxide Nanofibers and Their Energy Applications" where they focused on metal oxide, a nanofiber which has attracted considerable research interest for processing both one-dimensional nanometer scale morphology and unique chemical and electrical properties. A variety of their practical applications in light-emitting diodes, liquid crystal displays, solar cells, and gas sensors have been demonstrated in this contribution. With the electrospinning technique, it provides a rapid and facile way to fabricate nanofibers with diameter several orders of magnitude smaller than that produced by conventional spinning methods. They also discussed on the fabrication of ultrathin metal oxide nanofibers by the electrospinning technique, where the priority was given to zinc oxide nanofibers. Major parameters affecting the morphology and diameter of the nanofibers were also investigated systematically. The effect of calcination condition on chemical composition and crystallization of the electrospun nanofibers was also addressed in this book. Authors C. S. Lee et al. have focused on "Synthesis and Characteristics of Carbon Nanofibers/Silicon Composites and Application to Materials of Li Secondary Batteries," where they approached on various synthesizing technologies of carbon nanofibers (CNFs) as well as chemical vapor deposition (CVD) technology. It used for hydrocarbon gas or carbon monoxide as a carbon source gas and pyrolyze it to grow CNFs on transition metal catalysts such as Ni, Fe and Co, has been regarded as the most inexpensive and convenient method to produce CNFs for industrial use. Authors D. Kolbuk et al. have described on "Tailoring of Architecture and Intrinsic Structure of Electrospun Nanofibers by Process Parameters for Tissue Engineering Applications." They approached on electrospinning process, which is commercially used to form nanofibers as scaffolds in tissue engineering. Similarities in morphology of electrospun nanofibers to the natural extracellular matrix, flexibility, and low cost of the process contribute to its use in regeneration of the cartilage, ligaments/tendons, muscles, and bones. Properties are tailored by the use of appropriate polymers: polyesters, their copolymers, and blends with natural biopolymers like gelatin, collagen, chitosan, or composites with nanoparticles. In the case of one-component fibers, factors strongly influencing the final diameter of the electrospinning jet include volumetric charge density, distance between the needle and the collector, needle diameter, and viscosity. Authors T. Behzad et al. have focused on "Bio Nanofibers" where they approached on cellulose nanofiber preparation methods from different sources by chemical treatments. They also described the effect of source variations and mechanical processes used in extraction procedure on nanofiber morphology and crystallinity, and chemical composition was evaluated in this contribution. Authors Lucie Bacakova et al. discussed on. "Nanofibrous Scaffolds as Promising Cell Carriers for Tissue Engineering" where they approached on tissue engineering and organs in the human organism, where experimentally used for reconstruction and regeneration of the blood vessels, myocardium and heart valves, skeletal muscle, skin, tendon and ligament, intestine, trachea and bronchi, bladder and urethra, liver, pancreatic islets, brain, spinal cord, optic system, and peripheral nerves. Furthermore, they studied the interaction of human bone-derived cells with nanofibrous scaffolds made of polylactide and its copolymer with polyglycolide, loaded with hydroxyapatite or diamond nanoparticles. They also constructed the novel nanofibers based on diamond deposition on a SiO_2 template and practically demonstrated their effects on the adhesion, viability, and growth of human vascular endothelial cells. Authors M. Yada et al. have focused on "Syntheses and Applications of Titanium Compound Nanofiber Thin Films" where they introduced the generation of titanium compounds with various nanostructures, including titanium phosphate nanobelts and titanate nanofibers on the surface of titanium metal plate, from the treatment of a titanium metal plate in aqueous solutions of various compositions. Various compositions and concentrations and different reaction temperatures and times are combined for chemical processes involving titanium metal and novel titanium compounds/titanium metal composites with various compositions and nanostructures. Here, it was applied research on developing composites that feature the characteristics of both nanostructured titanium compounds and titanium metal. Authors F. Yilmaz et al. have discussed on "Nanofibers in Cosmetics." They developed the cosmetic nanofibers based on the properties on higher surface area to volume ratios, lower diameter, high strength values, low basis weights, higher porosities, and small pore sizes for numerous applications. Excellent interaction with environment, increased loading capacity for agents, high-liquid absorption capacities, high oxygen, and water vapor permeability values are provided by the characteristic properties of nanofibers.

Besides, nanofibers have potential applications in medicine and drug delivery, including artificial organ components, tissue engineering, implant materials [9], injured area dressing, and medical textile nanofiber materials. Lately, scientists have executed that nano-size fiber meshes could be utilized to function with HIV-1 viruses and be capable to be organized as a contraception. In injured area, healing fibers accumulate at the wounded-site and put, depiction the body's particular growth features to the injured-spotted area. Shielding nano-materials including sound absorption materials, shielding clothing over chemical as well as biological warfare agents, and chemi- and bio-sensor applications for identifying toxic and carcinogenic as well as hazardous environmental un-friendly chemical agents were utilized. Nanofibers have also been utilized in pigments for cosmetics as coloring fiber materials. Applications in the textile industry include sport apparel, shoes, climbing, rainwear, outer-wear garments, and baby diapers [10]. Nanofibers comprise antibodies in napkins with several biohazards and chemicals which signal by altering color. Filtration method for potential applications includes heating ventilation and air conditioning (HVAC) system filters, high-efficiency particulate air (HEPA), ultralow penetration air (ULPA) filters, air, oil, fuel filters for automotive, filters for beverage, pharmacy, medical applications, and filter media for new air and liquid filtration applications, such as vacuum cleaners. Fibrous carbon nanomaterials have attracted the substantial attention of researchers [11]. In the last 1960s, carbon nanofibers were introduced as one of the significant industrial implemental nanomaterials for existing science and technology which have been made from different carbon reactant precursors via spinning method. Polyacrylonitrile (PAN) has been utilized as the key reactant precursor with various functionalization as well as modification in producing or processing fibrous materials. Isotropic and anisotropic mesophase pitches and phenolic resins have also been reactant precursors for active carbon nanofibers. A chemical vapor deposition (CVD) method has also formulated carbon nanofibers with a nanostructure and significant chemical and physical properties that are changed from those made via catalytic melt spinning (vapor-grown carbon fiber; VGCF). In the center of VGCFs, thin tubes containing conventional carbon multilayers were executed [12] which were lately reported to be formed by arc discharging [13–15]. The method utilized for the fabrication of VGCFs was effectively functionalized to prepare CNTs [16]. The diameters of CNTs are very low in the nanometer range for single-wall CNTs, in contrast to the μm-range diameters of carbon nanofibers. CNTs are ruminated to be an significant nanomaterial for the improvement of up-to-date nanomaterials, due to carbon nanofibers have substances the improvement of contemporary nanotechnology. Electrospinning has been utilized to make nanofibers of different fiber polymers and diameters. It is a moderately simple method to produce unremitting fibers from fibrous polymer precursor solutions. Carbon fibers are made by electrospinning and carbonization with encapsulation on their nanostructure and characteristic properties in relation to their potential applications, after a short clarification on the circumstance and situations for electrospinning, and some fibrous polymers [17,18].

Nanotechnology of fibrous material is the understanding and controlling of matter at dimensions in nanoscale, where unique phenomena enable novel and significant applications. Nanofibers from cellulose and lignocelluloses play a key role in the nanotechnology field. The development of cellulose nanofibers has attracted significant interest in the last few decades owing to the unique characteristics they endow such as high-active surface-area-to-volume ratio, high Young's modulus, high tensile strength, and low coefficient of thermal expansion [19]. For environmental awareness and the international demand for green technology, bionanocomposites have the potential to replace present petrochemical-based fiber materials. The use of natural fibers instead of traditional reinforcement materials such as glass fibers, carbon, and talc provides several advantages including low density, low cost, good specific mechanical properties, reduced tool wear, and biodegradability [20]. Nanofibers of composites, polymers, and materials are recently used for various significant applications with various compositions in different physical and chemical properties. Nanofibers of doped metal oxides (CdO-ZnO) were prepared by wet chemical method at low temperature in basic medium. Later on the CdO-ZnO, nanofibers were used as photocatalyst for mineralizing the colored reactive Remazol brilliant orange 3R dyes, where it exhibited better photocatalysis than commercially available P25-TiO_2 materials [21]. In vitro, carbon nanofiber microbiosensor were practically developed for selective and sensitive dopamine neurotransmitter and supported copper-graphene oxide nanocomposite onto glassy carbon electrode using conducting coating binders by in situ chemical reduction [22].

Finally, we believe that this book offers broad examples of existing developments in recent development of nanofiber technology research and an excellent introduction to polymer, materials, and composite nanofibers for their potential applications. This work aims to bridge the gap between undergraduate, graduate, and researches in polymers, materials, composite, as well as biomedical sciences, in order to initiate researchers into various nanofiber studies in as straightforward way as possible and to introduce the scientist to the opportunities offered by the applied science and technology fields. It will provide review of the state-of-the-art techniques and advances of fiber researches and bio-nanotechnologies. Perspective authors were invited to present their novel ideas and recent advanced developments in the field of polymers, materials, or related fields. The primary target audience for the book Nanofiber Research - Reaching New Heights includes students, researchers, technologists, physicists, chemists, biologists, engineers, and professionals who are interested in nanofibers and associated topics.

Author details

Mohammed Muzibur Rahman

Address all correspondence to: mmrahmanh@gmail.com

Center of Excellence for Advanced Materials Research (CEAMR) & Chemistry Department, Faculty of Science, King Abdulaziz University, Jeddah, Saudi Arabia

References

[1] Camillo DD, Fasano V, Ruggieri F, Santucci S, Lozzi L, Camposeo A, Pisignano D. Nanoscale, 2013, 5:11637–11642.

[2] Zhou FL, Gong RH. Polymer International. 2008;57:837–845.

[3] Textile World. Nano Technology and Nonwoven. November 2003;P52

[4] Bhat G, Lee Y. *Recent advancements in electrospun nanofibers*. Proceedings of the Twelfth International Symposium of Processing and Fabrication of Advanced Materials, Ed. TS Srivatsan & RA Vain, TMS. 2003.

[5] Li D, Herricks T, Xia Y. Applied Physics Letters. 2003;83:4586.

[6] Theron A, Zussman E, Yarin AL. Nanotechnology. 2001;12:384.

[7] Li D, Wang Y, Xia Y. Nano Letters. 2003;3:1167.

[8] Reneker DH, Chun I. Nanotechnology. 1996;7:216.

[9] Nagy ZK, Zsombor K, Balogh A, Vajna B, Farkas A, Patyi G, Kramarics A, Marosi G. Journal of Pharmaceutical Sciences. 2011;101:322–332.

[10] Pourdeyhimi B. Topic of the month: commercialization potential of nanofiber textile membranes. May 5, 2012.

[11] Inagaki M, Yang Y, Kang F. Advanced Materials. 2012;24:2547–2566.

[12] Oberlin A, Endo M, Koyama T. Journal of Crystal Growth. 1976,32:335.

[13] Iijima S. Nature. 1991;354:56.

[14] Iijima S, Ichihashi T. Nature. 1993;363:603.

[15] Bethune DS, Kiang CH, Devries MS, Gorman G, Savoy R, Vazquez J, Beyers R. Nature. 1993;363:605.

[16] Endo M, Muramatsu H, Hayashi T, Kim YA, Terrones M, Dresselhaus MS, Nature. 2005;433:476.

[17] Greiner A, Wendorff JH. Angewandte Chemie International Edition. 2007;46:5670.

[18] Teo WE, Inai R, Ramakrishna S. Science and Technology of Advanced Materials. 2011;12:013002.

[19] Chirayil CJ, Mathew L, Thomas S. Review of Advanced Materials Science. 2014;37:20–28.

[20] Visakh PM, Thomas S. Waste and Biomass Valorization. 2010;1:121.

[21] Rahman MM, Asiri AM, Youssef TE, Marwani HM. Material Express. 2016;6:137–148.

[22] Khan A, Khan AAP, Asiri AM, Rub MA, Rahman MM, Ghani SA. Microchimica Acta. 2014;181:1049.